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SPH SIMULATIONS OF EARLY AND LATE SUPERHUMPS

S. Kunze[1]

RESUMEN

La hidrodinámica de partículas suavizadas es un método Lagrangiano para la solución de ecuaciones hidrodinámicas. Utilizamos aquí este método para simular el disco de acreción en novas enanas con cocientes muy bajos de masa, $q < 0.25$, típicos de sistemas SU UMa donde el disco de acreción puede llegar a ser excéntrico y estar en precesión durante una superexplosión, lo cual conduce a variaciones periódicas de brillo: las llamadas superjorobas. Se examinan dos fenómenos: primero, las superjorobas tardías, es decir, la ocasional permanencia de superjorobas mucho después del retorno al reposo, vistas por ejemplo en OY Car e IY UMa. Esto es debido a la variación de brillo de la región de manchas calientes, mientras el disco excéntrico continúa en precesión en el reposo; segundo, la ocurrencia de superjorobas tempranas en la superexplosión de WZ Sge. En este caso fuerzas de marea comprimen el borde del disco y la disipación de marea conduce a una estructura de picos dobles en la curva de luz orbital durante las etapas tempranas de la superexplosión.

ABSTRACT

Smoothed particle hydrodynamics is a Lagrangian method for the solution of the hydrodynamic equations. Here this method is used to simulate the accretion disk in dwarf novae with very low mass ratio, $q < 0.25$, typical for SU UMa-type systems where the accretion disk can become eccentric and precessing during a superoutburst, leading to periodic brightness variations, so-called superhumps. Two phenomena are examined. First the late superhumps, i.e., the occasional persistence of superhumps well after the return to quiescence, seen e.g. in OY Car and IY UMa. This is due to a varying brightness of the hot spot region, as the eccentric disk continues to precess in quisecence. Second, the occurence of early superhumps in the superoutburst of WZ Sge. Tidal forces compress the rim of the disk, the tidal dissipation leads to a double-peaked strucure in the orbital light curve during the early stage of the superoutburst.

Key Words: **ACCRETION, ACCRETION DISCS — BINARIES: CLOSE — HYDRODYNAMICS — METHODS: NUMERICAL — NOVAE, CATACLYSMIC VARIABLE**

1. INTRODUCTION

Superhumps (SHs) are periodic brightness variations, first discovered in SU UMa stars during their bright, long superoutbursts. SHs are a sign of the slow prograde precession of an eccentric accretion disk. The SH period, a few percent longer than the binary orbital period, is the beat period of the precession and the orbital periods, $\frac{1}{P_{\rm sh}} = \frac{1}{P_{\rm orb}} - \frac{1}{P_{\rm prec}}$. The growth of the eccentricity is due to a 3:1 resonance between the outer disk and the secondary. For systems with small mass ratio $q < 0.25$ the disk rim can reach this radius. Precessing disks in CVs have been well studied with smoothed particle hydrodynamics (SPH) simulations, especially the superhump phenomenon (e.g. Murray 1996, Kunze et al. 1997).

2. LATE SUPERHUMPS

The superoutbursts of SU UMa stars can be understood within the thermal-tidal instability model (Osaki 1989). After the disk has accumulated sufficient matter during quiescence, a thermal instability is triggered when the density reaches a critical value for the ionisation of hydrogen, and a normal outbursts takes place. Occasionally, the disk edge reaches the resonance radius during the outburst, and the tidal instability can set in, distorting the disk shape, and leading to an energetic superoutburst with superhumps. The SH maximum occurs when the secondary passes the bulk of the disk, releasing energy via viscous dissipation. In some systems, a periodic variation of brightness is detected also some time after return to quiescence, although with smaller amplitude and shifted in phase about 0.5 with respect to the normal superhumps (e.g. Hessman et al. 1992, Patterson et al. 2000). Using eclipse mapping methods, Rolfe et al. (2001) were able to identify hot spot region as the source of these late SH light in IY UMa. This effect was simulated with SPH by feeding an accretion disk via Roche lobe overflow. After 80 orbital periods the disk started

[1]Institut f. Astronomie und Astrophysik, U. Tübingen, Germany.

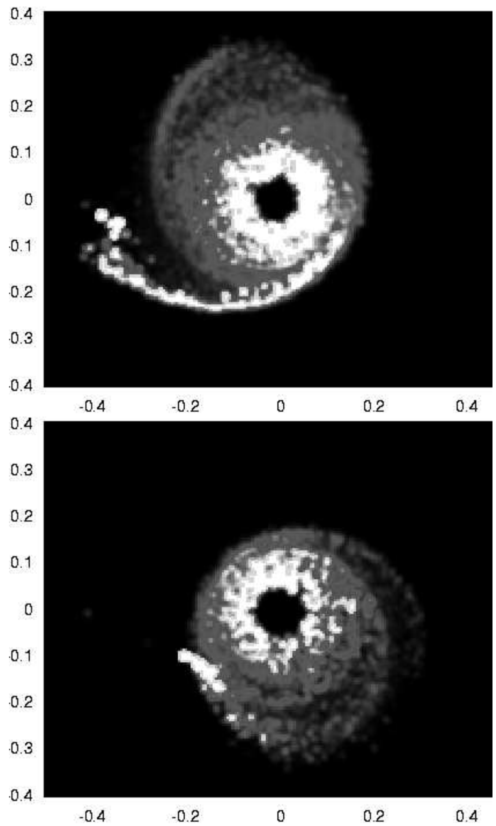

Fig. 1. Viscous dissipation in the disk at time of superhump maximum. The seconadry is to the left. Upper panel: normal superhump. The source of the superhump light is an extended spiral structure. lower panel: late superhump. The late superhump light source is the hot spot region, where the acrretion stream hits the disk rim.

to precess. The strong tidal interaction leads to enhanced accretion onto the white dwarf and depletion of the disk. The following return to quiescence was modeled by lowering the viscosity in the disk. The precession of the disk continues in qiescence, leading to a modulation of the hot spot brightness with the SH period, as the energy release in the hot spot region depends on the relative velocity of the stream and the disk rim.

3. EARLY SUPERHUMPS

In the early stages of the superoutbursts of WZ Sge stars, a peculiar type of photometric humps can be observed (first detection by Patterson et al. 1981). After about ten days these early SHs, or early humps, are replaced by the normal SHs. Early superhumps appear with the binary orbital period. Osaki and Meyer (2002) suggest that the early humps are due to a 2:1 resonance in the accretion disk. Only in systems with very low mass secondaries the disk can reach the 2:1 resonance. This explains why this effect is seen only in WZ Sge systems. The disk's response to the 2:1 resonance is a two-armed spiral pattern (Lin & Papaloizou 1979). The observed double-peaked orbital lightcurve is thought to be a sign of the tidal dissipation in the spiral arms. In order to investigate this, an SPH simulation was set up in the following way. The disk, initially a ring of matter at the circularisation radius, and was left to spread out under the action of the viscous shear forces. As the edge of the disk reaches the 2:1 resonance region, the expected spiral structure begins to build up. Taking into account the high inclination of WZ Sge, and assuming that a considerable fraction of the tidally dissipated energy is radiated away radially, the pseudo-lightcurve of figure 2 can be extracted, showing the typical double-humped shape. A more detailed study, including the transition to normal SHs, is under way.

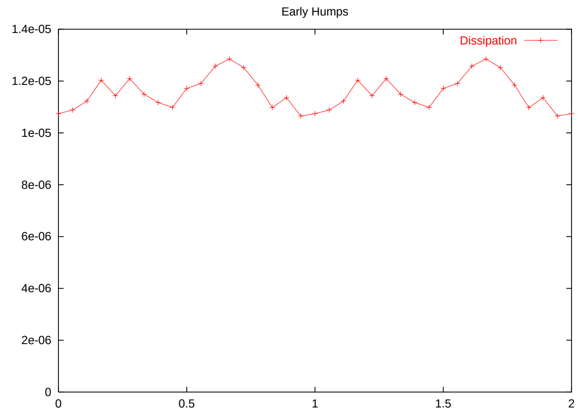

Fig. 2. Early Superhumps: Pseudo-lightcurve from the outer part of the disk, folded over the orbital phase. Dissipation in code units.

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